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Simple Model Frameworks for Explaining Inefficiency of the Clean Development Mechanism

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Abstract

The Clean Development Mechanism (CDM) is an offset mechanism designed to reduce the overall cost of implementing a given global target for greenhouse gas (GHG) emissions in industrialized "Annex B" countries of the Kyoto Protocol. This paper discusses various ways in which CDM projects do not imply full offset of emissions, thus leading to an overall increase in global GHG emissions when considering the Annex-B emissions increase allowed by the offsets. The authors focus on two ways in which this may occur: baseline manipulation; and leakage. Baseline manipulation may result when agents that carry out CDM projects have incentives to increase their initial (or baseline) emissions in order to optimize the value of CDM credits. Leakage occurs because reductions in emissions under a CDM project may affect market equilibrium in local and/or global energy and product markets, and thereby increase emissions elsewhere. Remedies against these problems are discussed. Such remedies are more obvious for the baseline problem (where one is simply to choose an exogenous baseline independent of the project) than for the leakage problem (which is difficult to prevent, and where a prediction of the effect must rely on information about overall market equilibrium effects).

This paper—a product of the Environment and Energy Team, Development Research Group—is part of a larger effort in the department to study overall economic implications of offset markets for greenhouse gas emissions. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at jstrand1@worldbank.org.

Simple Model Frameworks for Explaining Inefficiency of the Clean Development Mechanism

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I Introduction

The Clean Development Mechanism (CDM) is an "offset mechanism" under the UNFCCC's Kyoto Protocol. Its main objective is to reduce the overall global costs of implementing a given target for greenhouse gas (GHG) emissions in higher-income countries (those so-called Annex B countries that have signed the Protocol).[2] This is done by parties in Annex B countries paying parties in non-Annex B countries to reduce their emissions; these reductions are in turn credited against a given emissions quota for the respective Annex B country, thus allowing emissions to increase (be higher than otherwise) in the latter country.

It is important to have in mind that the main objective of CDM is not to reduce global GHG emissions, given that the emissions reduction targets in Annex B are guaranteed to be met. Its objective is instead to reduce the cost of implementing a given global emissions reduction, by shifting implementation costs from (high-cost) high-income countries, to (low-cost) low-income countries. In that sense, the task of CDM is to keep GHG emissions neutral while reducing costs. We will here however argue that CDM typically does not keep emissions neutral: emissions are instead increased, via a series of mechanisms to be considered. This is due to a number of flaws of the CDM mechanisms, some specific to CDM, but most probably common to all "offset mechanisms". The purpose of this paper is to study, and categorize, some main cases where such effects are likely to be important.

CDM consists of individual projects for evaluation and eventual approval, each of which is designed or presumed to contribute to reductions in global GHG emissions. For a given CDM project, and the CDM mechanism overall, to have the desirable effect on global GHG emissions, four questions all need to be answered in the negative:

1. Would the project have been carried out in the absence of CDM and associated financing?

2. Does the existence of CDM lead firms (or others that carry out particular CDM projects) to increase their "baseline emissions" beyond a level otherwise chosen?

3. Does the existence of CDM lead to policies of governments in CDM-executing countries that lead to increased GHG emissions, relative to those chosen if CDM had not existed?

4. Will carrying out the project lead to "spillover effects", or "leakage", by directly or indirectly increasing GHG emissions elsewhere, in this economy or in the world economy?

To answer all these four questions negatively, strong requirements are need. First, existence of the finance mechanism under CDM must be *both necessary and sufficient* for the "project" to be carried out. Secondly, there must be *no (partial or general) positive equilibrium spillover effects on other emissions ("leakage"),* in this or other markets. Thirdly, firms' "baseline emissions" (prior to implementing CDM projects), and governments' climate or environmental policies, must be *unaffected by CDM*.

[2] A further, secondary, objective of CDM is to secure financing to middle- and lower-income countries for energy efficiency improvements, energy technology projects, and other efforts to simultaneously reduce GHG emissions and support development, generally and in the energy sector specifically.

The possible sources of failure of CDM to implement the required emissions reductions, based on the points 1-4 above, may need some elaboration. We focus on three broad points.

1. The effect of CDM financing for individual projects

For individual projects CDM must, to have the desired effect (of reducing GHG emissions globally), be the factor that actually triggers project implementation. For this to be the case, the project cost in the host country must lie in a particular range: sufficiently high for the project not to be carried out in the absence of CDM, but sufficiently low to make the project viable under CDM. Only the first of these limits is of concern here. One here encounters a problem of asymmetric information. The host country is likely to know much more than an outside regulator about such costs, making it virtually impossible for the regulator to uncover the true project cost. Consider the "project" of building a hydropower plant and at the same time retiring an equally large coal-fired power plant. In this case, two issues come into play: CDM financing is necessary for viability of the hydropower plant; and closing down the coal-fired plant is contingent upon building the hydro plant. Needless to say, these questions are difficult or impossible for a regulator to answer in individual cases.

A further issue for individual projects is that their baselines can be manipulated. This is a phenomenon already recognized in the literature, and will be the major topic in Section II below.[3] A firm, preparing for a CDM project, will be interested in having a high "startout" (or baseline) emission rate, so as to make possible a large reduction in emissions when the project is implemented. As we se below, this baseline effect is likely to eliminate part, or in extreme cases even all, of the emissions-reducing effect of the CDM project. CDM regulators are likely to be aware of the problem, but may not have the informational basis to address it, and may often not even have the incentives to do so.

2. Effects of CDM for domestic policy

A strategic policy effect of CDM may arise when a host government, seeking to maximize its return from potential CDM projects, in response modifies its environmental and climate policy, making it laxer than otherwise. CDM projects must in principle be evaluated relative to some baseline, typically taken as exogenous by regulators. The problem is that such baselines can be manipulated by country policies, and not only by the firms implementing CDM projects. Consider a country where carbon emissions in urban areas are coupled with other emissions that lead to severe health problems. The country may then have incentives to tighten its environmental policy regardless of its interest in reducing carbon emissions. It may however fail to do so when CDM financing is a possibility. By failing to tighten policy, more projects may become CDM viable, and each project may be "larger" (as baseline emissions are larger), thus permitting a better overall exploitation of CDM-related revenue. This obviously involves asymmetric information, where outsiders most likely have no way of finding out what would be "counterfactual" policies, in the absence of CDM.

A question is whether strategic behavior with respect to baselines can be expected for both the CDM executing firm, and the host government. As argued below, this need not be the case. When the executing firm maximally exploits its strategic possibility to increase its baselines, there is "nothing left" for the government to do, as long as the objective functions of the CDM

[3] See Bhom (1994), Hagem (1996, 2009), Walker and Wirl (1994), Wirl et al (1998), and Fischer (2005). Some of this literature discusses Joint Implementation (working solely within the group of Annex B countries), which however has, for our purposes, properties virtually identical to those of CDM.

project host and the host government are perfectly aligned. However, when host firms do not, or are not able to, increase their baselines appropriately, there may be an additional role for their governments, in the form of overly lax environmental policies.

3. Spillover effects on emissions elsewhere ("leakage")

Spillover or leakage effects result from changes in overall supply and/or demand, for output in the CDM-executing sector, or in energy markets. Considering first effects via output markets, any possible spillover effects will depend on whether the project takes place in a domestic sector, or in a sector facing international competition, and in addition on various demand and supply relationships. When a domestic sector is affected, a supply reduction is likely to lead to a higher market output price in the sector, which may lead other firms in the sector to increase their outputs, and emissions. Any secondary GHG emissions increases will then also be realized in the domestic market. When the target for the project is an internationally traded good, most or all emissions increases will instead take place in other countries, as foreign supply increases to "take over" the market lost by the closed-down domestic firm.

Considering next energy markets, effects will also depend on whether the market is local, or global, and in addition on demand and supply responses. The analysis of such issues will be the topic of Section III below. Spillover effects, we will show, is then likely to result when a project reduces the demand for fossil fuels, and this lowers the market price of fossil fuels, globally (most likely for oil), or only locally (more likely for natural gas and coal). Such price reductions are likely to spur demand elsewhere, thus partly or fully eliminating the primary effect on emissions.

II Net effects of CDM projects on GHG emissions when baselines can be manipulated

We will in this section discuss how individual CDM-executing firms may manipulate the levels of their baseline emissions, and the effects of such manipulation on global GHG emissions. This discussion includes the consideration that baselines can be affected through government environmental policies (including taxes, subsidies and regulations). Throughout this discussion we take the view that the CDM regulator (the CDM Executive Board, or CDMEB) simply takes the observed emissions levels, and observed environmental policies, in CDM host countries as exogenous. This is overly naïve as it takes away all possibility for the CDMEB to respond strategically to the host's actions. It should thus be viewed more as a starting point for discussion, a first step toward a complete analysis.[4] The discussion will also be kept at an abstract level and with less of a view to quantitative implications; we wish to set out the nature of incentives involved, and how these may affect baselines.

1. Manipulation of individual baselines

A. Benchmark efficiency case

We start with an elementary model that will be expanded on later. Consider a "baseline" absent CDM, by which we mean a firm producing a good and emitting carbon initially, and

[4] Concrete examples of manipulation of baselines may be harder to find just due to the problem of asymmetric information, whereby the CDM regulator (and the public) will have difficulty telling when a given baseline is appropriate or not. Wara (2008) however indicates that such manipulation was highly likely for some of the largest CDM projects to date, the Chinese HFC-23 capture projects.

no consideration is made for offset market possibilities. Assume that the firm has a production function of the simple Cobb-Douglas form

(II.1.1) $$X = E^{\beta}$$

where X is the firm's output, E its energy input, and β the elasticity of output with respect to energy inputs. We thus abstract from other factors (viewing them as constants).[5] Assume that the producer faces a given price p per unit of output, and a given price z plus a possible excise tax t per unit of the energy input (which may be zero). Consider first the base case with no scope for utilizing the CDM market. The profit function for the firm is simply

(II.1.2) $$\Pi(0) = pE^{\beta} - (z+t)E$$

which, when maximized with respect to E, yield the following solution for the energy input:

(II.1.3) $$E(0) = \left(\frac{\beta p}{z+t}\right)^{\frac{1}{1-\beta}}$$

Inserting this into the profit function yields the reduced-form profit

(II.1.4) $$\Pi(0) = (1-\beta)\beta^{\frac{\beta}{1-\beta}} p^{\frac{1}{1-\beta}} (z+t)^{\frac{-\beta}{1-\beta}}$$

Consider next government policy, which consists of setting the energy tax t. Assume a stripped-down case where the government in question is subject to no externality effect of energy consumption (assuming only climate effects, which are ignored by the government).[6] There is neither any particular need to tax energy for tax revenue reasons. Furthermore, the government takes input and output prices as given in world markets, and these prices cannot be affected by its policy.[7] From the basic Pigou theory of externalities, the government's optimal solution is then to set a zero tax t.

All this is of course well-known and almost trivial: in the standard "baseline" solution with no externalities there is no environmental tax on energy, and the baseline solution itself is socially optimal (given no externalities).

B. Carbon offset financing via CDM with production closedown

Assume now, alternatively, that this firm faces the possibility of obtaining CDM financing for offsetting its energy consumption, and thus its carbon emissions (assuming that fossil-fuel energy is initially consumed). We will in this section consider a particularly simple case where the "CDM project" consists of closing down the firm and thus, presumably, "offsetting" all its (fossil-fuel) energy input. It is here natural to think of a coal-fired power plant which is replaced by an equally large power plant based on non-fossil fuels (nuclear, hydro or other renewable energies), where the new plant emits no GHGs, and where it

[5] This will be subsequently expanded.

[6] There may here in principle be co-benefits for the country (such as less local pollution) when energy consumption drops. This is ignored here; it would add nothing fundamental to our story.

[7] See Strand (2008) for a model where there are such effects, with the implication that the government may wish to impose a tax on the energy input, under assumptions which are in other respects the same.

operation profits are exactly zero (or where the "old" project is normalized with profits relative to that of the new plant).[8] Assume a production period λ before the CDM project can be realized, and during which the firm's "baseline emissions" are established. The firm is credited for the reduction in its energy consumption over a following period of length $1-\lambda$.[9] A key aspect of our analysis is to assume that the firm may *adapt strategically*, in the initial period λ, in preparation for closing down in period $1-\lambda$. Intuitively, when the firm sets its energy input at a higher initial level, there is "more room" for reducing this consumption, and thus, possibly, more to gain through CDM. Assume that the quota price awarded to the firm when carbon emissions are offset through a CDM project is assumed to be exogenous, equal to q. The overall profit of the firm from choosing a CDM project is then

$$\Pi(P) = \lambda(pE^{\beta} - (z+t)E) + (1-\lambda)qE \tag{II.1.5}$$

Maximizing Π(P) with respect to E now yields the following solution for the optimal energy input, E:

$$E(P) = \left(\frac{\beta p}{z(P)+t}\right)^{\frac{1}{1-\beta}} \tag{II.1.6}$$

where

$$z(P) = z - \frac{1-\lambda}{\lambda}q \tag{II.1.7}$$

The subsequent possibility of "selling" the project in the CDM market here reduces the effective energy price, and more so the greater is $((1-\lambda)q)/\lambda$. The case $z(P) < 0$ is clearly a possibility (although it does not correspond to an economically meaningful solution); in particular when λ is small and q large relative to z. This underlines that one can expect substantial pressure from firms to expand their baselines in preparation for CDM offsets.

We will find that it is here still optimal for the government to set t = 0, as long as the firm behaves optimally, both the firm and government face the same sets of exogenous parameters, and the government has no specific stake (apart from that of the firm) in the CDM mechanism nor its revenue. There are then no "externalities" that need correction by the central government.

A question is however whether the baseline derived here, with an "artificially high" rate of emissions, will be accepted by CDM regulators. In theory, the basis for calculating offsets ought to be emissions in the absence of CDM altogether, here, energy consumption and emissions under the benchmark case, given by (II.1.3). But an obvious asymmetric information problem arises: it is practically impossible for CDM regulators to observe the "correct" level of emissions given by (II.1.3), when emissions are actually given by (II.1.6).

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[8] Another type of CDM projects that may fit with this model are HFC-23 projects, in China and elsewhere, as discussed in Wara (2008). The related issue 1 above (CDM need to be necessary and sufficient for project implementation), often difficult to separate from the baseline manipulation issue, here also arises.

[9] λ and 1-λ can here be interpreted as simply the relative length of the "baseline" period and CDM project period, respectively, or discounted values of the same.

When will the firm choose to sell its activity as a CDM project, and when not? The condition for a CDM project to be preferred can be written as[10]

(II.1.8)
$$q > \left(\frac{1-\lambda^*}{1-\lambda} \lambda \right) z$$

where $\lambda^* = \lambda^{\frac{1-\beta}{\beta}}$

Here β would typically be no greater (in most cases less) than one half, so that $\lambda^* < \lambda$. Thus typically, $q > \lambda z$. Consider two alternative values for β, namely $\beta = ½$, and $\beta = 1/3$, while we assume $\lambda = ½$. (so that the baseline period and CDM implementation period are equally long). In the first of these two cases, condition (1.8) reduces to $q > \lambda z = z/2$. In the second case, the condition is $q > (1+\lambda)\lambda z = 3z/4$. Considering instead $\lambda = 1/3$ (where the CDM implementation period is twice as long as the baseline establishment period; which is probably more realistic), we find in the same two cases for β, $q > z/3$, and $q > 4z/9$. Note that in the latter two cases, the CDM quota price, q, can be less than the basic energy price, z, and a CDM project that implies closing down production completely, is still favourable.

In our framework, CDM will raise overall emissions from the firm and over the unit period in question, whenever $\lambda E(P) > E(0)$. The condition under which this holds is

(II.1.9)
$$q > \frac{\lambda}{1-\lambda}\left(1-\lambda^{1-\beta}\right) z$$

This is always the case when q is large relative to z. Consider a numerical case, with $\lambda = ¼$ (so that one-fourth of the unit period establishes the baseline, and three-fourths consist of the CDM implementation period), and $\beta = ½$ (so that the firm is very energy intensive). The condition is then $q > (1/6)z$ (the CDM quota price is one-sixth of the energy price). In this particular numerical example, overall energy consumption then increases despite production taking place during only one fourth of the period, and no production takes place during the CDM implementation period. Energy consumption during the initial production period is then at least four times as high, as a result of the firm's strategic adaptation to the ensuing CDM project phase. This is of course an extreme case; it however illustrates that the pressure to increased baselines can be very considerable.

This example also illustrates another issue: For the numerical example studied, with $\beta = ½$, whenever a CDM project is viable (condition (II.1.8) holds), condition (II.1.9) will also hold. In other words, any viable CDM project will imply that overall emissions increase: the project is always entirely counterproductive given the objective of global emissions reductions resulting from the project.

2. Uncertain and costly project implementation

We now extend this basic model in two ways: by assuming, first, that CDM financing is no longer certain. We consider two possibilities. First, we assume that the firm's energy consumption is fully flexible, and can be changed at will without cost within the project

[10] We are here ignoring transaction costs associated with establishing a CDM project. This will be discussed later.

period. The second case involves assuming that the energy technology must be determined, at the start of the period, for the entire period, so that, once the technology is set, energy consumption is proportional to output.

A. Fully flexible output

Here, the energy input can be changed, at no cost and at any time within the period, along the production function (II.1.1). After a fraction λ of the period is passed, the firm will know whether a CDM project is realized, and this occurs with probability $\rho < 1$. If a CDM project is not realized, the firm produces as normal for the rest of the period, and is permitted to adapt its energy output to the new situation (without possibility of CDM). Expected profits of such a firm are

(II.2.1)
$$\begin{aligned}\Pi(F) &= \rho\left[\lambda(p(E(F))^{\beta} - (z+t)E(F)) + (1-\lambda)qE(F)\right]\\ &+(1-\rho)\left[\lambda(p(E(F))^{\beta} - (z+t)E(F)) + (1-\lambda)(p(E(0))^{\beta} - (z+t)E(0))\right]\end{aligned}$$

Π(F) is now maximized with respect to E(F) and E(0). This is easily seen to yield the solutions (II.1.3) for E(0), while the solution for E(F) is found as

(II.2.2)
$$E(F) = \left(\frac{\beta p}{z(F)+t}\right)^{\frac{1}{1-\beta}}$$

where

(II.2.3)
$$z(F) = z - \rho\frac{1-\lambda}{\lambda}q$$

Compared to (II.1.6), the firm now chooses a lower value of its baseline energy input, E(F), as the effective energy price in the baseline period, *z(F)* from (II.2.3), is higher since there is only a probability $\rho < 1$ that the "premium" CDM quota payment q will be realized in the second period. Secondly, now only a fraction ρ of firms actually obtain CDM status and financing. Moreover, the overall profitability of CDM versus the status quo is reduced by the administrative cost C.

B. Inflexible output

In this alternative case we assume that the firm's output, and its energy input, must be determined at the start of the period, for the entire period, and regardless of future CDM status that the firm stays in business.[11] Thus only one level of energy input, E(U), will be determined, not two. Note that with certain CDM financing this is of no fundamental consequence, as A CDM-seeking firm would in any case shut down for certain after the baseline establishment period of length λ. Now, however, such a firm will stay in business until the end of the period, in the event that CDM financing is not obtained. This implies that

[11] Here, thus, the production scale must be established initially together with the energy input, at the start of the baseline period and throughout the CDM implementation period, given that the firm is to stay in business.

a “compromise” level of E must now be found. The expected profit function of the firm is now given by

(II.2.4)
$$\Pi(U) = \rho\left[\lambda(p(E(U))^{\beta} - (z+t)E(U)) + (1-\lambda)qE(U)\right] + (1-\rho)\left[p(E(U))^{\beta} - (z+t)E(U)\right]$$

Maximized with respect to E(U) this yields the following solution for E(U):

(II.2.5) $$E(U) = \left(\frac{\beta p}{z(U)+t}\right)^{\frac{1}{1-\beta}},$$

where

(II.2.6) $$z(U) = z - \rho\frac{1-\lambda}{\lambda'}q,$$

where *λ’ = ρλ + (1-ρ) > λ*. The main change relative to (II.1.6)-(II.1.7) is here the parameter ρ, which is generally less than unity, and which reduces the last term in (II.2.6), thus increasing the effective energy price, z(U). The reason is obvious: since CDM project acceptance is uncertain, the firm will not adapt fully to this eventuality but will select a technology that implies a compromise between the CDM case and the baseline case. Thus, generally, E(U) is less in this case.[12]

To consider the effect of CDM on energy use in this case, we must now consider that only a fraction ρ of the firms are able to carry out CDM projects, while a fraction 1-ρ will operate “as usual” but with an increased energy consumption. To study whether CDM increases or reduces overall energy consumption among firms that seek CDM certification, observe first that the average energy consumption in such firms is now

(II.2.7) $$E_A(U) = \lambda' E(U),$$

recognizing that a fraction 1-ρ of these firms will operate throughout the period, with the more energy intensive technology chosen at the start of the period. We can write

(II.2.8) $$E_A(U) = \lambda'(\beta p)^{\frac{1}{1-\beta}}\left(z - \frac{1-\lambda'}{\lambda'}q\right)^{-\frac{1}{1-\beta}}$$

where we note that *λ’ > λ*, and more so the smaller is ρ. We see that $E_A(U) = E(0)$ from (II.1.3), in the limiting case where λ’ = 1 (the case with no CDM possibility). The smaller is *λ’*, the greater *is ρ(1-λ)*, the expected fraction of the time that production is closed down as a result of CDM, from the point of view of any one of the firms whose behavior is affected by the CDM mechanism.

[12] It is here of course also less likely that we will have the unrealistic case where z(U) is negative.

When $E_A(U)$ increases in response to λ being reduced, energy consumption increases as a result of CDM. Comparing $E_A(U)$ to $E(0)$, we find, in fashion very similar to (II.1.9), that this holds given that

$$q > \frac{\lambda'}{1-\lambda'}\left(1-(\lambda')^{1-\beta}\right)z \tag{II.2.9}$$

(II.2.9) cannot hold when λ' is small (in particular, it cannot hold when *λ'* is close to or below $q/(z+q))$, implying that $\rho(1-\lambda)$ (the fraction of the time that production is closed down for firms affected by CDM) is close to one.

When CDM certification is uncertain, more firms will adapt their outputs and energy inputs to the existence of CDM, than those that carry out CDM projects. Presumably, this is the typical situation. From (II.2.9), in effect a modified version of (II.1.9), we may derive a range of values for q over which emissions increase with the existence of CDM projects, and more so, the more firms are affected by incentives to seek CDM financing (where in expectation $1/\rho$ firms adapt to the CDM possibility, for each firm that obtains CDM financing).

3. Endogenous energy technology

A. Basic model

We now expand the above model by assuming that firms' energy input can be modified not only by reducing the amount of energy consumed, E, but also by choosing a production technology that makes energy use more or less efficient in terms of producing output. We introduce an (energy-related) production factor R given by

$$R = HE \tag{II.3.1}$$

where E is energy consumption (proportional to carbon emissions), and H is a measure of efficiency of the energy technology applied. Assume that it is more costly to apply a technology with higher H, so that total "cleaning inputs", or "energy technology inputs", are given by

$$C = H^{\gamma} E \tag{II.3.2}$$

where γ is a cost factor. Assuming that it is progressively more costly to implement more energy efficient technologies, is the same as assuming $\gamma > 1$. We assume no fixed costs nor irreversibilities in implementing C, e g because the technology can be rented at a given rental rate at any given time.

Firms' basic profits (in a case absent CDM) can be expressed as

$$\Pi(0) = pR^{\beta} - zE - vC = p(HE)^{\beta} - zE - vH^{\gamma}E\ . \tag{II.3.3}$$

v is here the (rental) price per unit of the energy technology input, and z as before the basic energy price. Note that the basic energy cost is higher here than in sections 1-2 due to the added cost term in (II.3.3); this will alter the solutions somewhat. We will now disregard a possible tax on the energy input, on the presumption that firms' and the host government's preferences are aligned as in sections 1-2 above.[13]

Maximizing *Π(0)* with respect to E and H yields the first-order conditions

(II.3.4) $$\frac{d\Pi}{dE} = p\beta H^{\beta}E^{\beta-1} - z - vH^{\gamma} = 0$$

(II.3.5) $$\frac{d\Pi}{dH} = p\beta H^{\beta-1}E^{\beta} - v\gamma H^{\gamma-1}E = 0$$

From these we find

(II.3.6) $$H = \left(\frac{1}{\gamma-1}\frac{z}{v}\right)^{\frac{1}{\gamma}}.$$

E can be expressed in terms of z and v as follows:

(II.3.7) $$E = kp^{\frac{1}{1-\beta}}z^{-\frac{\gamma-\beta}{\gamma(1-\beta)}}v^{-\frac{\beta}{\gamma(1-\beta)}}$$

where *k* is the following constant:

(II.3.8) $$k = \beta^{\frac{1}{1-\beta}}\gamma^{-\frac{1}{1-\beta}}(\gamma-1)^{\frac{\gamma-\beta}{\gamma(1-\beta)}}.$$

(II.3.7) implies that *E* falls when factor prices, z and v, increase.

Note that since $\gamma > 1$, the exponent to *(z+t)* is greater than unity in absolute value; thus an increase in energy cost by one percent reduces energy demand by more than one percent. It is however smaller in absolute value than the equivalent coefficient in (II.1.3). Note however that the sum of the coefficients to *z* and v in (II.3.7) equals *1/(1-β).* Thus when z and v increase proportionately, the effect is basically the same as in section 1 (and, from (II.3.6), *H* will be constant).

Note that *E* is always falling in the cost, v, of the cleaning technology. *H* is also falling in v; thus an increase in *v* unambiguously reduces the energy-related productive input *HE*. We also find that when z changes, *R = HE* will change as follows:

(II.3.9) $$\frac{dEl(HE)}{dEl(z)} = -\frac{(\gamma-1)(1-\alpha)}{\gamma(1-\alpha-\beta)}$$

which is negative: thus *E* falls, and by more than *H* increases in relative terms, when the energy price to producers is increased.

[13] We later come back to cases where these preferences may not be aligned, and where a tax or subsidy from the government may be warranted.

We also see that a proportional increase in z and v leaves H invariant, and reduces E as follows:

(II.3.10) $$\frac{dEl(E)}{dEl(z)}(dEl(z) = dEl(v)) = -\frac{1-\alpha}{1-\alpha-\beta}.$$

B. Private and social optimality with CDM project option

We now extend this discussion to the case where CDM project approval can be sought, and concentrate first on the case of certain approval. Assume as a benchmark that the firm is fully free to set its baseline output level, as well as the CDM implementation period. We are thus no longer restricting the CDM implementation output to be zero, as we did in sections 1-2. We consider two cases: a) the firm is free to adapt both H and E optimally, in both the establishment period and the implementation period; and b) the firm is required to keep H at the pre-established level, and constant throughout the baseline establishment period and the CDM implementation period.

Optimal H and E

Assuming that the firm will continue to produce throughout the CDM implementation period, but possibly at a reduced level, the relevant profit expression for the firm is (where subscripts P and C stand for baseline and CDM implementation period values)

(II.3.11)
$$\Pi(H) =$$
$$\lambda[p(H_P E_P)^\beta - zE_P - vH_P{}^\gamma E_P] + (1-\lambda)[p(H_C E_C)^\beta - zE_C - vH_C{}^\gamma E_C] + (1-\lambda)q(E_P - E_C)$$
$$= \lambda[p(H_P E_P)^\beta - \left(z - \frac{1-\lambda}{\lambda}q\right)E_P - vH_P{}^\gamma E_P] + (1-\lambda)[p(H_C E_C)^\beta - \left(z+q\right)E_C - vH_C{}^\gamma E_C]$$

This expression is maximized with respect to H_P, E_P, H_C and E_C. The conditions with respect to E_P and E_C are, normalizing now by setting $p = v = 1$:

(II.3.12) $$\frac{d\Pi}{dE_P} = \lambda[\beta H_P{}^\beta E_P{}^{\beta-1} - \left(z - \frac{1-\lambda}{\lambda}q\right) - H_P{}^\gamma] = 0$$

(II.3.13) $$\frac{d\Pi}{dE_C} = (1-\lambda)[\beta H_C{}^\beta E_C{}^{\beta-1} - \left(z+q\right) - H_C{}^\gamma] = 0$$

The solutions for E_P and E_C are given from a modified version of (II.3.7) as follows:

(II.3.14) $$E_P = k\left(z - \frac{1-\lambda}{\lambda}q\right)^{-\frac{\gamma-\beta}{\gamma(1-\beta)}}$$

(II.3.15) $$E_C = k(z+q)^{-\frac{\gamma-\beta}{\gamma(1-\beta)}}$$

with k given by (II.3.8).

The solutions for H are derived in similar way as for (II.3.6), and can be written on the form

(II.3.16) $$H_P = \gamma_1\left(z - \frac{1-\lambda}{\lambda}q\right)^{\frac{1}{\gamma}}$$

(II.3.17) $$H_C = \gamma_1\left(z + q\right)^{\frac{1}{\gamma}}$$

where $\gamma_1 = (\gamma\text{-}1)^{-(1/\gamma)}$.

We here find that $H_P < H_C$, implying that *a firm seeking CDM financing will choose an (inefficient) low-technology energy efficiency solution in the baseline period.* As a result, the energy technology choice will exacerbate the increase in baseline energy consumption and emissions.

Constant H

Consider next the case where H is independent of q and given by (II.3.6). Again we normalize by setting $p = v = 1$. Noting that $H^{\gamma} = z/(\gamma\text{-}1)$, we then simply replace H_P and H_C by this expression for H. The conditions with respect to E_P and E_C are now:

(II.3.18) $$\frac{d\Pi}{dE_P} = \lambda(\beta H^{\beta} E_P{}^{\beta-1} - \frac{\gamma}{\gamma-1}z + \frac{1-\lambda}{\lambda}q) = 0$$

(II.3.19) $$\frac{d\Pi}{dE_C} = (1-\lambda)(\beta H^{\beta} E_C{}^{\beta-1} - \frac{\gamma}{\gamma-1}z - q) = 0$$

The solutions for E_P and E_C are found as follows:

(II.3.20) $$E_P = k_1 z^{\frac{\beta}{\gamma(1-\beta)}}\left(\frac{\gamma}{\gamma-1}z - \frac{1-\lambda}{\lambda}q\right)^{-\frac{1}{1-\beta}}$$

(II.3.21) $$E_C = k_1 z^{\frac{\beta}{\gamma(1-\beta)}}\left(\frac{\gamma}{\gamma-1}z + q\right)^{-\frac{1}{1-\beta}}$$

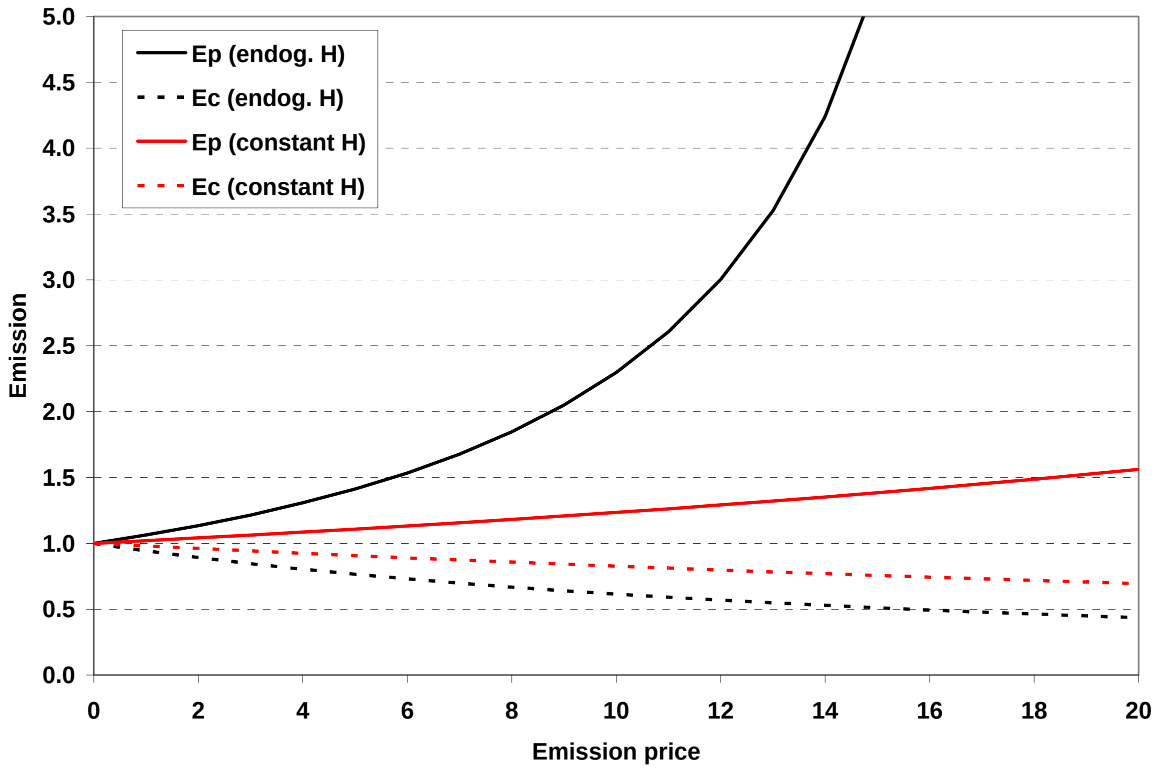
where $k_1 = \beta^{\frac{1}{1-\beta}}(\gamma-1)^{-\frac{\beta}{1-\beta}}$.

We here find that E_P is generally greater in (II.3.20) than in (II.3.14), while E_C is generally smaller in (II.3.21) than in (II.3.15). In Figure 1 below, we simulate the solutions for E_P and E_C, in the case with endogenous H, and constant H, respectively.[14] We there see that the difference between the two cases is generally greater for E_C. Thus, when firms have the

[14] In the example of the simulation, we set $\beta = 0.5$, $\gamma = 1.25$, $\lambda = 0.5$, and $z = 20$.

capability to alter their energy technology in the short run, they will choose a more variable energy input in the baseline period versus the CDM implementation period, and in particular choose a higher energy input in the baseline period, as a “less sophisticated” (and cheaper) energy technology is chosen in this period. In the CDM implementation period it will be opposite, as the energy technology will then be relatively more sophisticated when it can be altered in the short run.

Figure 1: Emissions under baseline (E_P) and in the CDM implementation period (E_C), in cases with constant H, and endogenous H, respectively



Source: Own simulations
Notes:
Emissions in the case of no CDM are normalized to unity.
Parameter values applied for simulations: $\beta = 0.5$, $\gamma = 1.25$, $\lambda = 0.5$, and $z = 20$.

The practical implication of this result is that when firms are foreseeing CDM financing, and may choose their baselines, firms will tend to choose a baseline (pre-CDM) energy technology that is less efficient than otherwise (chosen in the absence of CDM financing; in our model, prevailing under case B). Drawing also on conclusions from Section II.2 above, where not all firms seeking CDM financing were assumed to obtain it, one could also here easily visualize cases where inefficient energy technologies are established and retained over time, due to availability of the CDM option, also in firms that do not actually obtain CDM financing.

4. Remedies

The basic remedy for the troubles outlined in sections above would be for the CDM regulator to set a predetermined baseline tied to “objective” criteria, and based on an (hopefully unbiased) assessment of the firm’s “objectively correct” emissions. This would make the firm's return from CDM project approval independent of energy use in the baseline period, and the problem discussed here, of inefficiently high baselines, would not arise. One key problem with such a procedure is under asymmetric information that individual firm baselines cannot be predicted without error. This leaves one with the possibility that the baseline will be under-predicted, and the firm under-rewarded for its actual CDM project implementation. If such under-rewarding is sufficiently serious, one runs the further risk that some firms that should have done so, choose not to seek CDM financing.

The other, more sophisticated and elaborate, remedy is for the regulator to apply an optimal regulatory scheme where the asymmetric information problem is explicitly taken into consideration. Deriving an optimal regulatory scheme, building on principles established by Laffont and Tirole (1993), requires that the distribution over baseline emissions for the firms in question is known.[15]

A set of deeper and more subtle issues however also arise. One question is whether regulatory agents, including the CDMEB, really have incentives to "dig sufficiently deep" on these issues; there may exist fundamental agency problems whereby the preferences of CDM executers, their controlling and auditing agents, and the CDMEB (including their auditors and consultants), are overly aligned.[16] We will not elaborate more on this, only note that it is a potential problem with the practical implementation of any offset mechanism.

III Leakage and global emissions effects of CDM projects

In part II above we considered the possibility of an inadequate primary effect of CDM on GHG emissions in non-Annex B countries. We will in this part of the paper assume that CDM fulfils this basic promise, as a "first-order" effect. However, "second-order" effects on emissions, elsewhere in the same economy or internationally, may partly eliminate these beneficial first-order effects. Such additional effects are termed "leakage", which has been an important concern for unilateral reduction of GHG emissions. Carbon leakage can occur through two main channels – via product markets (e.g. relocation of industries), or via fossil fuel markets. Carbon leakage via fossil-fuel markets can occur if emission reductions take place (at least partly) through reduced demand for fossil fuels. As the fossil-fuel markets are international, reduced demand in one region will typically lead to reduced prices of fossil fuels and hence increased demand and emissions outside the region. The market effects are however likely to differ somewhat by fuel: while the oil market is fully international, the markets for natural gas and coal tend to be more local, with greater price variations between submarkets.

We will argue that the CDM mechanism increases the likelihood of carbon leakage through the fossil fuel markets if the CDM project involves reduced use of fossil fuels. That is, a CDM project combined with a corresponding increase in the cap on Annex B emissions will most likely increase global emissions, even if the CDM project itself is a real emission reduction project.[17] Thus, an important premise of the CDM mechanism may be violated.

[15] See also Fudenberg and Tirole (1992) for a game theoretic basis for related regulatory design problems.
[16] One may argue that this problem applies more to the CDMEB's auditors and consultants, than to the CDMEB itself. An incident exemplifying this problem is the suspension by the CDMEB, in November2008, of the Norwegian consulting firm DNV, one of the largest CDM auditors globally, for poor and biased performance in evaluating the ability of prospective CDM projects to deliver GHG emissions reductions. It is however difficult to know whether this was a "sincere" act by the CDMEB, and not an act of pure "conscience cleaning".
[17] We do not consider the additionality problem here, and assume that the emission reductions from the CDM project would not have taken place without the CDM mechanism.

Carbon leakage associated with the CDM mechanism has earlier been studied by Bollen et al. (1999) and Kallbekken (2007), using global CGE models. See also Vöhringer et al. (2006) for a discussion if this issue. None of these papers provides an analytical study of leakage from CDM projects.

Given that a CDM project both reduces emissions in a Non-Annex B country *and* increases emissions in Annex B (because the cap is increased), we must consider leakage effects from both these emission changes. Emission reductions in Non-Annex B will typically lead to positive leakage, whereas emission increases in Annex B will typically lead to negative leakage. Note, however, that any net leakage must occur in Non-Annex B, because total emissions in Annex B are given by the (increased) cap.

1. One-market model

To illustrate we start with a very basic model of a fossil-fuel market. Consider a CDM project that reduces the use of fossil fuels (and thus emissions) in a specific firm. We may here consider two different cases, A and B. In case A, we assume that the fossil-fuel market is global, thus comprising both Annex B and Non-Annex B countries. In case B, there are no links between this fossil fuel market and those in Annex B.

A. One global fossil-fuel market

Here there exists only one fossil fuel, which is traded either in one global market or in two local markets. Assume first that the fossil fuel is traded in one global market. Then a CDM project that reduces energy consumption by Q^G in Non-Annex B will increase energy consumption in Annex B by exactly the same amount (with one good, consumption is completely defined by the cap). Thus, market equilibrium is maintained with unchanged price, supply and demand in Non-Annex B (outside the CDM project). Consequently, there is no net leakage of the CDM project.

B. Separate fossil-fuel markets in Annex B and Non-Annex B countries

This is the more interesting case here. First, note that there cannot be any (negative) leakage from Annex B in this case, simply because any net leakage must take place in Non-Annex B, and this is not possible when the fossil fuel markets are separated. Thus, we can concentrate on the effects of the CDM project in the Non-Annex B market.

Aggregate supply is represented by the supply function $Y(p)$, where p is the fossil fuel price. Aggregate demand, excluding consumption in the specific firm (denoted Q), is represented by the demand function $D(p)$. Market equilibrium before the CDM project is undertaken can then be expressed as:

(III.1.1) $$Y(p) = D(p) + Q.$$

Assume now that the CDM project is carried out, reducing the level of Q. Differentiating equation (1) and rearranging then gives:

(III.1.2) $$L = \frac{dD}{-dQ} = \frac{-D'}{Y' - D'} = \frac{-d}{y-d},$$

where lower case letters refer to elasticities (evaluated at that point). Note that $L=dD/(-dQ)$ denotes how much consumption of fossil fuel increases elsewhere in the market per unit reduction through the CDM project, i.e., the leakage rate.

We see that the leakage rate of the CDM project depends on the supply and demand elasticities in the market. If e.g. only the demand elasticity is close to zero, the leakage effect is insignificant. This could be the case if prices are regulated and the producers meet the demand of the consumers. On the other hand, if only the supply elasticity is close to zero, the leakage rate is close to 100 per cent, and so there is no net emission reduction by the CDM project. This could be the case if production is regulated by the government. Finally, if the supply and demand elasticities are equal in absolute value, we see that the leakage rate is 50%, i.e., net emission reduction is only half the gross reduction from the project.

The intuition is that the CDM project reduces local demand for the fossil fuel. In order to restore market equilibrium, either supply must decrease, demand from other users must increase, or both. With price-responsive supply and demand, the final outcome will be a combination of reduced supply, increased demand, and lower price, entailing a positive carbon leakage.

The model above is relevant if the CDM project simply reduces consumption of e.g. coal in a specific firm. Another typical CDM project is to replace coal power with renewable power. In order to analyse this, we consider an electricity market with both fossil and renewable plants. Equilibrium in the electricity market before implementing the CDM project can then be expressed as:

(III.1.3) $$Y^E \equiv FE(p^F, p^E) + Q + RE(p^E) = DE(p^E) \equiv D^E$$

where FE denotes fossil-based electricity production, RE renewable electricity production, and DE total electricity consumption. p^F and p^E denote prices of fossil fuel and electricity, respectively. Q denotes production from a specific fossil based power plant which can be replaced by a renewable plant through a CDM project.

Equilibrium in the fossil fuel market can be expressed as (ignoring conversion rates between fossil fuel and electricity in the power plant):

(III.1.4) $$Y^F \equiv YF(p^F) = FE(p^F, p^E) + Q + FF(p^F) \equiv D^F$$

FF denotes demand for fossil fuel outside of the electricity market, whereas YF denotes fossil fuel supply.

When the CDM project is implemented, Q will be reduced in equation (III.1.4) but not in equation (III.1.3) as it is replaced by a corresponding renewable plant. Still, the price of fossil fuel will change, and this will also affect the electricity market indirectly.

Differentiating equations (III.1.3) and (III.1.4), we obtain:[18]

$$\text{(III.1.5)} \quad L = 1 + \frac{dY^F}{-dQ} = 1 + \frac{y^F(d^E - \gamma^{RE} y^{RE} - \gamma^{FE} y^{FE})}{(\gamma^{RE} y^{RE} - d^E)(y^F + \delta^{FE} y^{FE} - \delta^{FF} d^{FF}) + \gamma^{FE} y^{FE}(y^F - \delta^{FF} d^{FF})},$$

where δ and γ denote market shares of respectively demand and supply in the two markets, while d and y denote demand and supply elasticities in the two markets.

It is easy to show that the leakage rate in equation (III.1.5) is between 0 and 1, but it is difficult to read more out of this equation without making further assumptions. If for instance all elasticities have the same absolute magnitude, it can easily be shown that the carbon leakage rate is between 33% and 50% (depending on the different market shares).[19] The leakage rate increases with the share of fossil based power in the electricity market (γ^{FE}), and decreases with the share of fossil going to the electricity market (δ^{FE}).

The table below illustrates the effects on the leakage rate of changing the assumptions about elasticities and market shares. The base case assumes equal elasticities (only the relative sizes of elasticities matter, not the absolute levels), γ^{RE}=1-γ^{FE}=0.1 and δ^{FE}=δ^{FF}=0.5, which gives a leakage rate of 44%. In the table we reduce one elasticity at a time by half, double γ^{RE} (to 0.2), or change δ^{FF} to 0.25 or 0.75.

Table 1. Leakage rates with different assumptions about elasticities and market shares

	Leakage rate
Base case (equal elasticities)	**44%**
y^F halved	61%
d^E halved	41%
y^{RE} halved	43%
y^{FE} halved	40%
d^{FF} halved	34%
γ^{RE} doubled	44%
δ^{FF} = 0.25	40%
δ^{FF} = 0.75	47%

Source: Own simulations

From Table 1, the two most important elasticities seem to be the supply elasticity of fossil fuel (y^F) and the demand elasticity of fossil fuel from consumers outside the electricity market (d^{FF}) (given that its share of fossil fuels is significant).

The intuition here is the same as above. When a coal power plant is replaced by a renewable plant, demand for coal is reduced in the coal market. Thus, the coal price is reduced, coal supply reduced, and coal demand outside the CDM project increased. Some of the increased coal demand comes from other coal power producers, leading to increased electricity supply

[18] We assume that $\partial FE / \partial p^F = -\partial FE / \partial p^E$.

[19] If the fossil-based plant is closed down and *not* replaced by a renewable plant, the leakage rate will be between 50% and 75% in the case with equal elasticities. In the basic model (equation (III.1.2)) we saw that the leakage rate would be 50% in the case with equal (absolute value of) elasticities. Note that only *relative*, not absolute, elasticities matter.

and lower prices of electricity. Other coal consumers also increase their demands because of the lower coal prices. The carbon leakage rate depends on how much coal demand increases outside the CDM project relative to the reduction brought about by the CDM project itself.

There are so far few concrete empirical studies that can illustrate the more exact magnitudes of leakage effects in different cases. One study of CDM projects in the electricity sector in India, Böhringer et al (2003), however, indicates a rate of leakage between 50 and 60 percent, due to market repercussions in the rest of the economy. This is well in line with likely figures from our simulations above.

C. Leakage from CDM vs. leakage from Annex B mitigation

The two cases examined in subsections A and B above are both extreme. Fossil fuel markets are not separated between Annex B and Non-Annex B, but they are neither completely global. A small shock to the market will typically have strongest effects on prices and demand/supply close to the source of the shock. For instance, a CDM project that reduces consumption of coal from an installation in India will most likely have stronger effects on coal supply and demand in India than in Germany. Thus, it may be reasonable to expect the total leakage effects to be somewhere in between the cases A and B above, and higher the more segregated the fossil fuel market in question is. In the next section we approach this issue by having one completely global fossil fuel, and one fossil fuel with no trade between Annex B and Non-Annex B.

A separate issue is that the effects giving rise to leakage may make it more difficult for Annex B countries to keep their emissions within the required limits. In particular, when Non-Annex B countries reduce their demands for fossil fuels, the price of fossil fuels traded internationally will drop and encourage increased fossil-fuel demand also in Annex B. This may increase the risk that some countries will “default” on their Kyoto obligations.[20] More stringent policy measures are then necessary to keep overall emissions within the required constraints.

2. Two-market model

In this section we will allow for some fossil fuel trade between Annex B and Non-Annex B. Let us assume that there are two fossil fuels. One is traded only in local markets (L) with no trade between Annex B and Non-Annex B markets, and the other is traded freely in a global market (G), with one common price. Following the discussion above, we examine the effects on global emissions of undertaking an additional CDM project, assuming that the CDM project increases the cap on Annex B emissions: If a CDM project gives Q credits, then the Annex B cap is increased by Q units. We assume that the cap on emissions in Annex B is implemented through a uniform price of carbon (τ). Market equilibria before the CDM project is carried out are then given by (with both fossil fuels measured in carbon units):

(III.2.1) $$Y_1^G(p^G) + Y_2^G(p^G) = D_1^G(p^G + \tau) + D_2^G(p^G) + Q^G$$

(III.2.2) $$Y_1^L(p_1^L) = D_1^L(p_1^L + \tau)$$

[20] In particular, Canada seems currently to be on the verge of default of its obligations under Kyoto, as its emissions are currently exceeding the required limit by more than 20 percent, and Canada is currently buying virtually no CDM quotas. The main point here is that if some Annex B countries have ratified Kyoto but default on their Kyoto obligations, leakage effects are likely also for these defaulting countries.

(III.2.3) $$Y_2^L(p_2^L) = D_2^L(p_2^L) + Q^L$$

(III.2.4) $$D_1^L(p_1^L + \tau) + D_1^G(p^G + \tau) = \overline{D_1}$$

where 1 and 2 denote Annex B and Non-Annex B respectively, and Q^G and Q^L denote potential CDM projects that reduce consumption of respectively the global and local fossil fuel in Non-Annex B. As seen from the equations, we disregard any substitution possibilities between the two fossil fuels.

Global emissions are given by

(III.2.5) $$E = \overline{D_1} + D_2^L + D_2^G + Q^G + Q^L .$$

Note that

(III.2.6) $$dE = dD_2^L + dD_2^G = \frac{\partial D_2^L}{\partial p_2^L} dp_2^L + \frac{\partial D_2^G}{\partial p^G} dp^G ,$$

since reducing Q^G or Q^L implies that $\overline{D_1}$ is increased accordingly.

From equation (III.2.6) we see that it is necessary to derive the price effects in the global market and in the local market in Non-Annex B. By differentiating the equations above and solving for dp_2^L and dp^G we get (small letters denoting elasticities):

(III.2.7) $$dp_2^L = \frac{1}{y_2^L - d_2^L} \frac{p_2^L}{D_2^L} dQ^L ,$$

from which follows:

(III.2.8) $$dD_2^L = \frac{d_2^L}{y_2^L - d_2^L} dQ^L ,$$

which we recognize from equation (III.1.2) above. Furthermore, we get for the price on the global fossil fuel:[21]

(III.2.9) $$dp^G = \frac{1}{\Delta} p^G p_1^L \left[-\delta_1^G d_1^G (y_1^L - d_1^L) \right] dQ^L + \frac{1}{\Delta} (p^G)^2 \frac{D_1^L}{D_1^G} \left[y_1^L d_1^L \right] dQ^G ,$$

where

$$\Delta = \Big[D_1^L p^G d_1^L y_1^L \left(\gamma_1^G y_1^G + \gamma_2^G y_2^G - \delta_1^G d_1^G - \delta_2^G d_2^G \right) +$$
$$D^G p_1^L \delta_1^G d_1^G \left(\gamma_1^G y_1^G y_1^L + \gamma_2^G y_1^L y_2^G - \delta_2^G y_1^L d_2^G - \gamma_1^G d_1^L y_1^G - \gamma_2^G d_1^L y_2^G + \delta_2^G d_1^L d_2^G \right) \Big] < 0$$

[21] In order to simplify the expressions somewhat, we assume from now on that the initial emissions tax in Annex B is small compared to the prices of fossil fuels. The main conclusions still hold if we relax this assumption.

and δ and γ denote market shares of demand and supply, respectively (in the global market).

The first bracket in the expression for dp^G is positive, and the second bracket is negative. Thus, p^G decreases if the CDM project reduces use of the global fossil fuel, and increases if the CDM project reduces use of the local fossil fuel.

The effects on emissions can now be expressed in the following way:

$$\text{(III.2.10)}\; dE = \left[\frac{d_2^L}{y_2^L - d_2^L} - \frac{p_1^L D^G}{\Delta} \delta_2^G \delta_1^G d_2^G d_1^G (y_1^L - d_1^L) \right] dQ^L + \left[\frac{p^G D_1^L}{\Delta} \frac{\delta_2^G}{\delta_1^G} d_2^G y_1^L d_1^L \right] dQ^G$$

The term in front of dQ^G is negative, whereas the two terms in front of dQ^L have different signs. From this we can conclude that a CDM project that reduces consumption of the global fossil fuel will unambiguously increase global emissions, while the effect of a CDM project that reduces consumption of the local fossil fuel is ambiguous.

The latter results may seem surprising, given the findings above for one single market. The explanation for the unambiguous leakage effect of a CDM project for the global fossil fuel is as follows: When the cap in Annex B is raised due to the CDM project, the first-order effect is to increase consumption of *both* fossil fuels. However, since consumption of the global fossil fuel in Annex B increases less than the decreased energy use due to the CDM project, the global fossil-fuel price falls. This leads to increased consumption of this fossil fuel in the rest of Non-Annex B, explaining the leakage effect. Note that the local market in Non-Annex B is unaffected in this case.

In order to say more about the effects of a CDM project for the local fossil fuel, we need to combine the two terms in front of dQ^L. We can then show that a sufficient but not necessary condition for positive leakage effect of a CDM project for the local fossil fuel is the following condition:

$$\text{(III.2.11)} \qquad \frac{\gamma_1^G y_1^G + \gamma_2^G y_2^G}{\delta_2^G d_2^G} \geq \frac{y_2^L}{d_2^L}$$

For instance, if the relationships between the supply and demand elasticities are the same for the two fossil fuels in Non-Annex B, and Non-Annex B is *not* a net importer of this fossil fuel, then the condition is fulfilled and leakage is strictly positive.

The intuition in this case is the following: When a CDM project takes place in a local market, we can distinguish between the effects in this local market and the effects elsewhere (because the local market in Non-Annex B is not connected to other markets), cf. the two terms inside the first bracket in equation (III.2.10). In the local Non-Annex B market we get positive leakage effects along the lines discussed in section A. Thus, if e.g. supply and demand elasticities are equal in absolute value, this leakage amounts to 50% of the CDM project. When the cap on Annex B emissions is increased, consumption of both fossil fuels increases here. This leads to a *negative* leakage effect in Non-Annex B for the global fossil fuel. However, if the cap increase is e.g. equally divided between the two fuels, the increased consumption of the global fossil fuel in Annex B amounts to only half of the CDM project. Consequently, even if the leakage rate of this particular consumption should be e.g. 50%, compared to the original CDM project the negative leakage effects amount to merely 25%. Thus, we end up with a positive leakage effect of (50-25) % = 25% in this case.

Although equation (III.2.10) in general terms indicates that positive leakage is more likely than negative leakage, one cannot rule out the possibility of negative leakage. This follows from the argument in the previous paragraph: If the positive leakage effects in the local market are small (either due to high supply elasticity or low demand elasticity), and the negative leakage effects in the global market are big, we may end up with a negative overall leakage rate.[22]

In the table below we show the leakage rate based on equation (III.2.10) for a CDM project for either the local or the global fossil fuel. As before, in the base case we assume equal elasticities. We also assume equal market sizes and market shares in the base case.[23]

As seen from Table 2 below, in the base case the leakage rate is 30% when the CDM project reduces consumption of the local fuel, and 20% when it reduces consumption of the global fuel. Econometric studies on price elasticities vary a lot, and it is difficult to conclude which are higher, demand or supply elasticities. The same ambiguity applies to elasticities in Annex B vs. Non-Annex B, and to elasticities of different fossil fuels. Table 2 shows effects of alternative assumptions, and the degree of leakage rate is found to depend significantly on these assumptions. The same applies to assumptions about market sizes.

Table 2. Leakage rate with one global and one local fossil fuel

	Q^L	Q^G
Base case	**30%**	**20%**
Annex B elasticities = 2 * Non-Annex B elasticities	36%	14%
Demand elasticities = 2 * Supply elasticities	33%	22%
Supply elasticities = 2 * Demand elasticities	22%	15%
Elasticities in global market = 2 * Elasticities in local market	25%	13%
Global market size = 2 * Sum of local market sizes	25%	13%
Annex B demand = 2 * Non-Annex B demand	36%	11%
"Oil and coal"[a]	31%	11%
"Fossil and non-fossil"[b]	-20%	20%

[a] Oil is the global fuel and coal the local fuel. Market shares/sizes are 60/40 and 40/60 for respectively oil and coal demand in Annex B vs. Non-Annex B. Equal elasticities.
[b] Fossil is global and non-fossil is local with no market response in Non-Annex B.
Source: Own simulations.

In the second-to-last row of Table 2 we assume that oil is the global fuel and coal the local fuel, and have used approximate market shares/sizes from 2007.[24] A CDM project that reduces consumption of the local fuel, coal, here has a leakage rate of 31%. In the last row we have assumed that local demand in Non-Annex B is completely unresponsive to demand. This

[22] This may be seen from equation (III.2.10) with either a sufficiently high supply elasticity of the local good (y_2^L) or sufficiently low demand elasticity of the local good (d_2^L).
[23] That is, demand in the global market equals combined demand in the two local markets, which themselves are equal in size.
[24] There is of course trading in coal between Annex B and Non-Annex B countries, but one cannot speak of one global coal market in the same way as for the oil market (mainly because of much higher transport costs relative to the value of the fuel). Still, this scenario should only be considered as illustrative.

could illustrate the effects of assuming global fossil fuel markets combined with mitigation of other greenhouse gases. If a CDM project reduces emissions of methane, fossil fuel markets are unaffected by this project. However, reduced mitigation in Annex B will have negative leakage effects in Non-Annex B, explaining the negative leakage effect in the table.

Above we concluded that the leakage rate could be negative when the CDM project reduces consumption of the local fuel, whereas a CDM project that reduces consumption of the global fuel always has a positive leakage effect. Nevertheless, from the table above we note that the leakage rate is highest in the former case in all scenarios listed except the last one. The intuition is that the first order leakage effect within Non-Annex B is lower when the market is global, as some of the market response takes place within Annex B (where total emissions are capped).

Finally, what if either both markets are local or both markets are global? In the former case we get the same conclusion as with one local fuel, cf. Section A. If both markets are global, leakage depends on the relative elasticities in the two markets. It can be shown that a CDM project that reduces consumption of fossil fuel *L* has a positive leakage effect if and only if:[25]

(III.2.12)
$$\frac{\gamma_1^G y_1^G + \gamma_2^G y_2^G}{\gamma_1^L y_1^L + \gamma_2^L y_2^L} > \frac{\delta_2^G d_2^G}{\delta_2^L d_2^L}$$

We see immediately that if the two markets are equal, there is no leakage (as in the case with only one market). More generally, there will be positive leakage if the CDM project takes place in the market with least elastic global supply and most elastic demand in Non-Annex B, and negative leakage otherwise. The explanation is as follows: The first order effect of a CDM project in market *L* is to reduce both global consumption and the price in market *L*, and to increase both global consumption and the price in market *G* (because the increased cap in Annex B is 'divided' between the two markets). If supply in market *L* is much less elastic than Non-Annex B demand, then there will be significant positive leakage in this market. The first order effect of reduced demand will mainly be followed by increased demand elsewhere in Non-Annex B. If supply in market *G* is much more elastic than Non-Annex B demand, then there will be little negative leakage in this market. The first order effect of increased demand in Annex B will be followed by increased supply and only small demand reduction in Non-Annex B. Thus, overall leakage is positive.

Note that since total Annex B demand is capped, demand elasticities in Annex B affect the *size* of the leakage, but not its sign.

3. Conclusions

The analysis above suggests that the CDM mechanism increases the likelihood of carbon leakage, at least when CDM projects reduce the use of fossil fuels. As long as some fossil fuel markets are not completely global, leakage from CDM projects will in most cases be higher than leakage from mitigation within Annex B.

The analysis shows that an important question is to what degree fossil-fuel markets are international, and to what degree price signals disperse in the market. This varies of course by fuel, depending not least on their transport costs. On the one hand, the oil market is global

[25] If the CDM project takes place for the other fossil fuel (*G*), the inequality is turned around.

with a more or less uniform price across countries. Gas markets are by contrast more divided due to significant fixed transport costs, and the greater need for long-term contracts in setting prices. The coal market, which is most relevant with respect to CDM, is global, but transport costs are higher than in the oil market. Thus, trade is more regional than in the oil market, and coal prices vary more across regions than in the oil market (this is also due to more quality differences). Consequently, price signals caused by reduced coal use through a CDM project will typically be strongest in the geographical proximity of the project, and thus leakage effects will also tend to be strongest there.

Moreover, end-users do not trade directly on the global market, and the difference between the end-user price and the world market price is not a fixed quantity but may respond to changes in domestic demand and supply, at least in the short to medium term. Thus, a certain reduction in demand within a national retail market will likely lead to larger price reduction in the domestic retail market than in the international market (in the short- to medium term). Thus, a disproportionate share of the leakage will take place domestically.

The obvious question, what to do to control and correct for the degree of leakage when awarding credits for emissions reductions from CDM projects, arises also here. Such a question may appear more difficult to answer here, than for the case of baseline manipulation dealt with in Section II of this paper. One basic difficulty is that the leakage effect is more elusive as an empirical phenomenon; it cannot readily be observed as it is scattered among a (very) large number of other economic agents, who increase their emissions due to market equilibrium effects, in local and/or global markets, and for both energy and final goods. Even more crucially, any particular incidence of leakage typically cannot be attributed to any one particular CDM project; leakage is more an overall market phenomenon with effects scattered over a large number (often millions) of economic agents. An understanding of the entire market structure is necessary to make such assessments, which will almost by definition be controversial. Better empirical work, in particular on pinning down the parameters discussed in our presentation, will enable a more precise assessment of leakage effects in individual cases, and thus the degree to which CDM projects should be credited.

Another difference in how to handle leakage, versus how to handle of baseline manipulation, is that while baseline manipulation can in principle be eliminate through appropriate strategies or policies directed at individual CDM projects or CDM as a mechanism, for leakage this is not possible. Leakage rather needs to be identified and quantified (through mechanisms and procedures indicated in this section of the paper), and emissions reduction credits awarded in accordance with the (model based) calculated net emissions effects. Such model-based crediting will tend to reward projects more correctly on the average, thus in particular discouraging some projects where these net gains are not sufficient to overcome project costs.

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